Superficial Venous Arterialization for Upper Extremity Limb Salvage

Eric H. Twerdahl, MD[1,2]; Scott M. Tintle, MD[1,3]

Abstract

Over the past several decades, venous arterialization has attracted renewed research and clinical interest in the treatment of patients with critical limb-threatening ischemia (CLTI) not amenable to endovascular or open revascularization. Upper extremity CLTI attributable to infrabrachial chronic arterial occlusive disease is an infrequently encountered problem in clinical practice for which no evidence-based treatment algorithm exists. Here we describe our approach to a patient with right upper extremity CLTI and limited arterial runoff into the hand. We performed an end-to-side anastomosis between the cephalic vein of the proximal forearm and the distal brachial artery, with complete mechanical valvulotomy of the arterialized vein. The operation yielded a satisfactory technical result, and the patient's wounds healed completely.

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KEY WORDS: upper extremity, critical limb-threatening ischemia, venous arterialization

Upper extremity critical limb-threatening ischemia (CLTI) is an infrequently encountered problem in clinical practice, with etiologies including hemodialysis access-related hand ischemia (ARHI),[1] hypoperfusion with associated use of systemic vasoconstrictors,[2] nonatherosclerotic arteriopathy,[3-5] thromboembolism,[3] percutaneous access-related thrombosis,[6,7] trauma,[6] and peripheral arterial occlusive disease (PAOD).[3-6,8] Among the patients presenting the greatest challenge are those with PAOD in the infrabrachial circulation, for whom endovascular or open revascularization options can be limited.

Arterialization of the human venous circulation was first attempted by San Martín y Satrústegui in 1902,[9] and recent decades have seen a proliferation of research and clinical interest in the use of deep venous arterialization (DVA) for the treatment of lower extremity CLTI.[10,11] Reports concerning the use of VA for the treatment of upper extremity CLTI are limited to single-institution or single-surgeon experience.[3,4,12] Here we present a description of superficial venous arterialization (SVA) for successful upper extremity limb salvage.

Case Report

A 60-year-old, White, right-hand-dominant man was transferred to a large military treatment facility for multidisciplinary management of gangrene affecting the second digit of his right hand. The patient's medical history was notable for coronary artery disease, hypertension, hyperlipidemia, chronic obstructive pulmonary disease, active cigarette smoking, end-stage renal disease, insulin-dependent diabetes mellitus, PAOD, and a poorly defined clotting disorder manifested by multiple instances of arterial and venous thrombosis. His surgical history was notable for bilateral and proximal transfemoral amputations attributable to PAOD and amputation of the left upper extremity distal to the elbow for complications of ARHI. He had been receiving hemodialysis 3 times weekly through a tunneled dialysis catheter. His outpatient medications included warfarin for the above-noted thrombophilia.

Following admission and initial medical stabilization, the patient underwent partial amputation of the right second digit. Over the ensuing several days, however, the residual digit was noted to have evidence of worsening ischemia (**Figure 1**). Subsequent evaluation included digital pressure measurements and a duplex ultrasound assessment. Pressures in the right first and third digits were 33 mm Hg and 28 mm Hg, respectively. Duplex ultrasound assessment of the right upper extremity arterial circulation demonstrated focal stenosis of the mid-brachial artery (**Figure 2A**); chronic total occlusion of the distal ulnar artery (**Figure 2B**); and diminished flow in the distal radial artery, manifested by a *tardus et parvus* waveform (**Figure 2C**).

Accordingly, a supra-aortic and right upper extremity angiogram was performed via right femoral access. The study demonstrated an area of focal severe stenosis of the mid-brachial artery (**Figure 3A**), which was treated with a balloon-expandable covered stent (**Figure 3B**). A completion angiogram of the infrabrachial circulation demonstrated limited arterial runoff into the hand (**Figures 3C** and **3D**). The patient was loaded with clopidogrel and maintained on a continuous infusion of intravenous heparin.

FIGURE 1. Preoperative photograph demonstrating ischemia of the residual right second digit. The purple marks indicate the surface anatomy of the distal cephalic vein.

Based on the results of the angiogram and subsequent mapping of the right cephalic and basilic veins, brachiocephalic SVA was thought to afford the best chance of limb salvage.

The operation commenced with circular amputation of the residual right second digit, with exposure of the second metacarpal head and shaft (**Figure 4**). The surface anatomy of the cephalic vein was marked with the guidance of ultrasound, and the vein was exposed along the length of the forearm. The metacarpal shaft was transected (**Figure 5**), and resection of the metacarpal head and shaft was completed (**Figure 6**). The distal brachial artery was exposed over a length of approximately 3 cm and circumferentially dissected (**Figure 7**). Tributaries of the exposed cephalic vein were ligated and divided, and the anterior surface of the vein was marked with methylene blue (**Figure 8**). The patient was systemically anticoagulated with a bolus of intravenous heparin. The proximal cephalic vein was transected, and the vein was instilled and dilated with a room-temperature solution of heparin (2500 units) and nitroglycerin (100 mcg) mixed in 500 mL of Ringer's lactate solution (**Figure 9**). Visible intraluminal valve tissue was sharply resected. Non-crushing vascular clamps were applied to the brachial artery, and a 1 cm longitudinal arteriotomy was made in the anterior aspect of the vessel. The cephalic vein was spatulated, and a standard end-to-side anastomosis was performed with 2 running sutures of 6-0 polypropylene (**Figure 10**). Flow was restored following

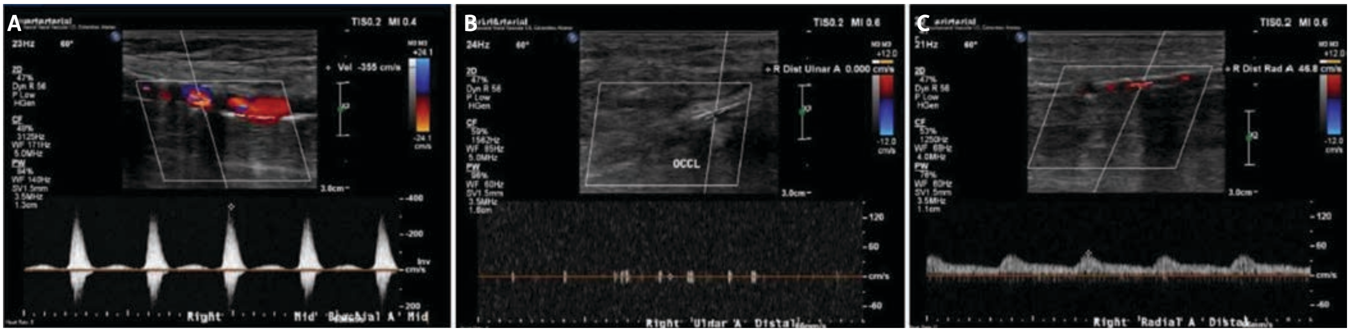

FIGURE 2. Preoperative duplex ultrasound assessment of the right upper extremity arterial circulation. A) Demonstration of focal stenosis of the mid brachial artery, with a peak systolic velocity measuring 355 cm/s. B) Demonstration of chronic total occlusion of the distal ulnar artery. C) Demonstration of a *tardus et parvus* waveform in the distal radial artery.

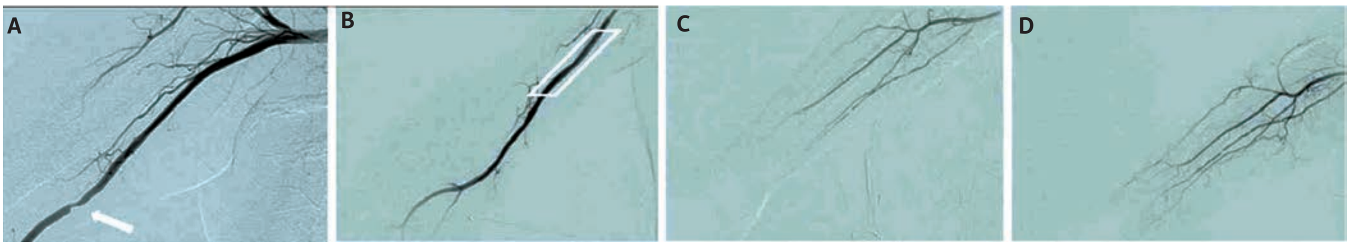

FIGURE 3. Preoperative angiogram of the right upper extremity arterial circulation. Access is via the right common femoral artery. A) Focal, severe stenosis of the mid brachial artery, indicated by the arrow. B) Brachial artery angiogram following treatment with a balloon-expandable covered stent (Viabahn VBX, Gore). The parallelogram indicates the location of stent placement. C) Post-treatment angiogram of the infra-brachial arterial circulation. D) Demonstration of limited arterial runoff into the hand.

FIGURE 4. Intraoperative photograph following circular amputation of the residual right second digit, with exposure of the second metacarpal head and shaft. The cephalic vein is exposed along the length of the forearm.

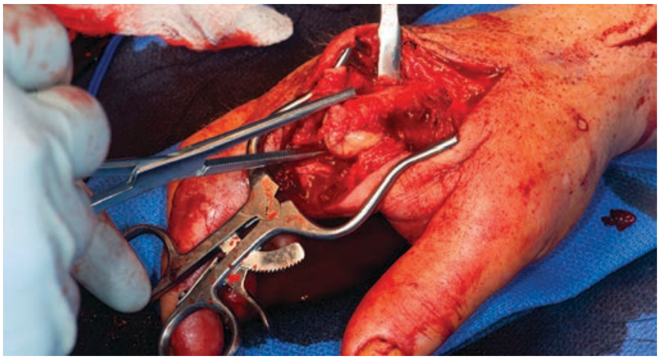

FIGURE 5. Intraoperative photograph demonstrating transection of the right second metacarpal shaft.

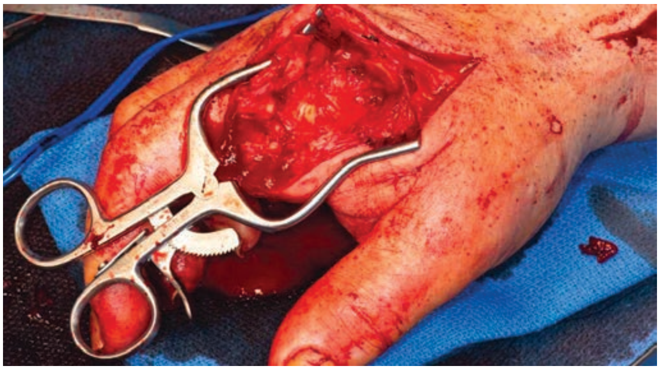

FIGURE 6. Intraoperative photograph following resection of the right second metacarpal head and shaft.

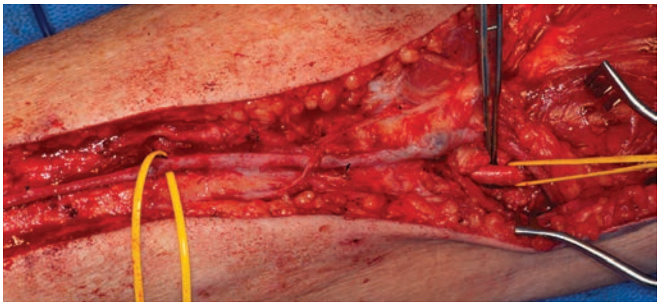

FIGURE 7. Intraoperative photograph demonstrating exposure and circumferential dissection of the distal right brachial artery.

FIGURE 8. Intraoperative photograph demonstrating the final vascular exposure. The anterior surface of the right cephalic vein is marked with methylene blue. Tributaries of the cephalic vein are ligated with sutures of 5-0 silk.

FIGURE 9. Intraoperative photograph following transection of the proximal right cephalic vein. The vein is then instilled and dilated with a room-temperature solution of heparin (2500 units) and nitroglycerin (100 mcg) mixed in 500 mL of Ringer's lactate solution. Intraluminal valve tissue visible through the open end of the cephalic vein is sharply resected.

appropriate flushing and de-airing maneuvers. Retrograde valve lysis of the cephalic vein proximal to the distal forearm was performed following introduction of a 1.5 mm LeMaitre valvulotome catheter (LeMaitre Vascular) through a transverse venotomy just large enough to accommodate the valvulotome catheter (**Figure 11**). Through the venotomy, a fine DeBakey vascular dilator was then passed in an antegrade direction to disrupt valves in the distal cephalic vein and exposed tributaries (**Figure 12**). The venotomy was closed with a single interrupted suture of 7-0 polypropylene, and a sterile Doppler probe was used to confirm arterial flow in the more distal superficial veins of the hand. Following an uncomplicated postoperative course, the patient was discharged on clopidogrel and warfarin.

At follow-up, pressures in the right first and third digits were measured to be 41 mm Hg and 43 mm Hg, respectively. Duplex ultrasound assessment of the arterialized right cephalic vein demonstrated a low resistance arterial waveform in the mid forearm (**Figure 13A**) and a low resistance arterial waveform with normal upstroke distal to the wrist (**Figure 13B**). The patient's wounds healed completely (**Figures 14A** and **14B**).

Discussion

Upper extremity CLTI is an uncommon though important problem in clinical practice. In the Hemodialysis Fistula

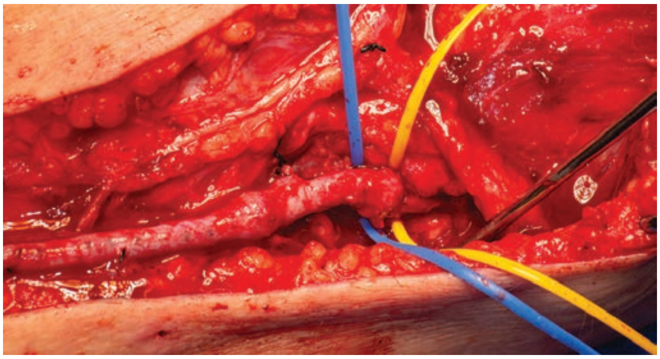

FIGURE 10. Intraoperative photograph following completion of an end-to-side right cephalic vein to brachial artery anastomosis. The anastomosis is performed with 2 running sutures of 6-0 polypropylene.

Maturation Study,[1] a multicenter prospective cohort study designed to identify predictors of arteriovenous fistula maturation, 4% of approximately 600 patients were found to have symptoms of ARHI requiring intervention. Other etiologies with which clinicians may be familiar include: hypoperfusion with associated use of systemic vasoconstrictors in patients admitted to the intensive care unit[2]; nonatherosclerotic arteriopathy, such as Raynaud's phenomenon, thromboangiitis obliterans, or vasculitis[3-5]; thromboembolism from intravenous drug abuse or atrial fibrillation[3]; percutaneous access-related thrombosis[6,7]; trauma[6]; hypothenar hammer syndrome[4,5]; and PAOD.[3-6,8] The risk factors for upper extremity PAOD are similar to those for lower-extremity PAOD and include: hypertension, hyperlipidemia, cigarette smoking, diabetes mellitus, and a family history of cardiovascular disease. Interestingly, however, patients with

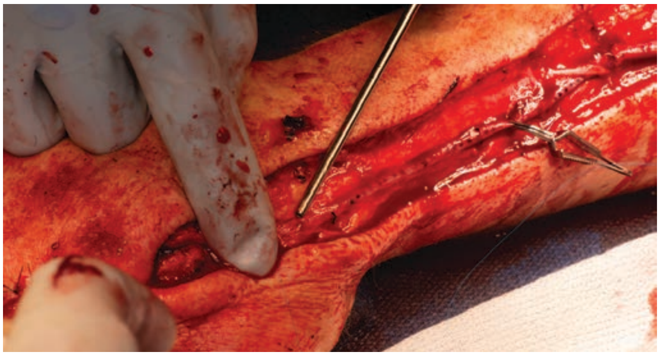

FIGURE 11. Intraoperative photograph following retrograde valve lysis of the right cephalic vein proximal to the distal forearm. The 1.5 mm LeMaitre valvulotome (LeMaitre Vascular) is introduced through a transverse venotomy just large enough to accommodate the valvulotome catheter.

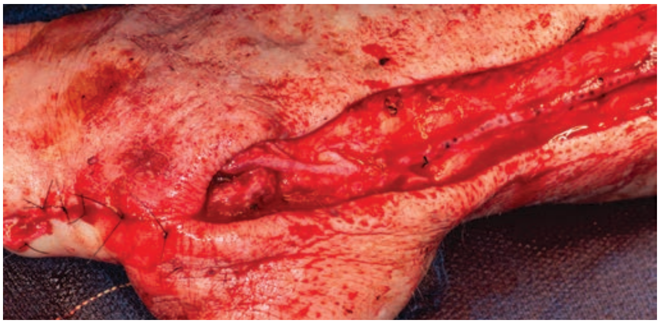

FIGURE 12. Intraoperative photograph following antegrade valve lysis of the distal right cephalic vein into the hand. Through the existing venotomy, a fine DeBakey vascular dilator is passed in an antegrade direction to disrupt valves in the cephalic vein and exposed tributaries. The venotomy is then closed with a single interrupted suture of 7-0 polypropylene. A sterile Doppler probe is used to confirm arterial flow in the more distal superficial veins of the hand.

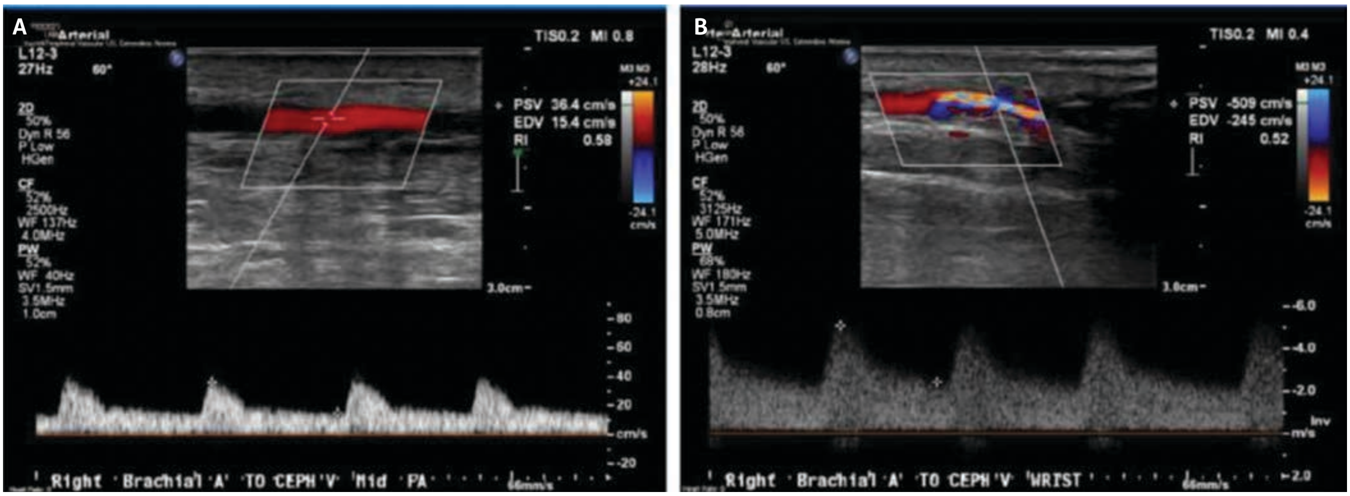

FIGURE 13. Postoperative duplex ultrasound assessment of the arterialized right cephalic vein. A) Demonstration of a low-resistance arterial waveform in the mid forearm. B) Demonstration of a low-resistance arterial waveform with normal upstroke distal to the wrist. The elevated peak systolic and end diastolic velocities are likely indicative of turbulent blood flow.

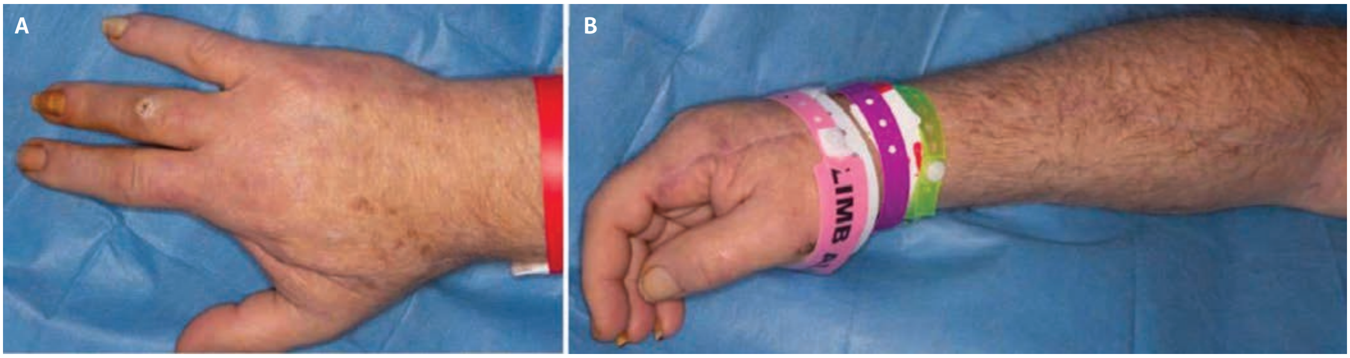

FIGURE 14. A) and B) Postoperative photographs demonstrating complete wound healing.

upper extremity PAOD are characteristically younger and more often female than patients with lower extremity PAOD.[6,8]

There is modest though instructive literature regarding arterial reconstruction in the management of upper extremity CLTI. In 2007, Hughes and colleagues[6] reported a prospective experience of 9 cases of arterial reconstruction proximal to the wrist, and in 1992 Nehler and colleagues[5] reported a retrospective experience of 17 cases of arterial reconstruction distal to the wrist. The underlying etiologies in the latter series were hypothenar hammer syndrome in 11 cases and PAOD in 6. The largest experience in the literature is that reported by Cheun and colleagues,[8] who described their management of 108 patients presenting to a single tertiary care center from 2006 to 2016. In their series, 93% of patients presented with tissue loss and the remainder with ischemic rest pain. Fifty-five patients underwent intervention (balloon angioplasty in 34 and infrabrachial bypass in 21), with the decision to intervene or not based on the adequacy of the distal runoff. Significantly more patients in the intervention group had healed wounds at 3 months, but there was no significant difference in the rates of major amputation between the intervention group and the nonintervention group.

Initial canine experiments with arteriovenous anastomosis were attempted by Frank in 1881[9] and Carrel and Berard in 1902.[13] In the latter experiment, reversal of the circulation in the saphenous vein was achieved by means of an end-to-end anastomosis between the femoral artery and saphenous vein in Scarpa's triangle. Encouraged by the technical result, Carrel offered the following foresight: "If normal nutrition of the limb were possible, and the results of the end-to-end anastomosis permanent, the operation would perhaps be proposed for the preventive treatment of gangrene following obliteration of the arteries." Arterialization of the human venous circulation was first attempted by San Martín y Satrústegui in 1902, and a 1913 description of "arteriovenous anastomosis for impending gangrene" by Goodman[9] included 15 consecutive cases, 6 of which he judged to be clinically successful.

The theory underlying the role of VA in limb salvage has been demonstrated in both canine and human models. In 1989, Graham and colleagues[14] assessed neovascularization in a canine model of arteriovenous reversal, finding significant increases in vascular density and nutritive flow based on angiography, transcutaneous oximetry, tritiated thymidine uptake, and histologic capillary density analysis. In a prospective study of 26 cases of femorotibial bypass with polytetrafluoroethylene in human patients, 14 of which were supplemented with an onlay arteriovenous fistula, Jacobs and colleagues[15] reported in 1993 that limbs treated with a fistula had significantly better nutritive skin perfusion than limbs treated without a fistula based on microscopic analysis of red blood cell flow dynamics in the capillary circulation.

The most recent decades have seen a proliferation of research and clinical interest in the use of DVA for the treatment of lower extremity CLTI. In 2020, Ho and colleagues[10] offered a comprehensive review of open, endovascular, and hybrid DVA techniques for lower extremity limb salvage, and the PROMISE II investigators,[11] writing last year in the *New England Journal of Medicine*, reported the results of a prospective, multicenter study of endovascular DVA in patients with CLTI not amenable to endovascular or open revascularization. Among the 104 patients included in the study, the limb salvage rate was 76%.

Reports concerning the use of VA for the treatment of upper extremity CLTI are limited to single institution or single-surgeon experience and include a 10-case series from Peters and colleagues in 2020[3] and a 6-case series in 1993 from King and colleagues.[4] In the former series, each patient was treated with an end-to-side cephalic vein to radial artery anastomosis at the wrist, with valve destruction induced only by arterial pressure. In the latter, 3 patients underwent end-to-side median basilic vein to brachial artery anastomosis with antegrade valvulotomy, and 3 underwent end to-side cephalic vein to radial artery anastomosis at the wrist. In a 2016 report, Zeng and Hammert[12] described their technique of brachiocephalic SVA, from which we developed our specific approach.

We performed a brachiocephalic SVA procedure in the case of a patient with upper extremity CLTI and no suitable distal target for infrabrachial arterial reconstruction. We used the brachial artery for inflow, given its larger diameter and absence of significant calcification, which made for a more favorable anastomosis than would have been achievable from a proximal infrabrachial artery. Moreover, we performed mechanical valve lysis over the entire length of exposed vein to ensure unimpeded arterial flow into the hand. The postoperative course was uncomplicated, and the patient's wounds healed completely.

Conclusions

The retrospective experience of Cheun and colleagues,[8] in which they found no significant difference in the rates of major amputation between patients with upper extremity CLTI treated with arterial revascularization and patients with upper extremity CLTI not treated with arterial revascularization, casts some doubt on the necessity of revascularization in the treatment of upper extremity CLTI attributable to PAOD. One might also consider the role of advanced wound care adjuncts, such as hyperbaric oxygen therapy. The relative infrequency of upper extremity CLTI attributable to PAOD means that an evidence-based treatment algorithm is likely to come about only by multicenter collaboration. In the meantime, clinicians should treat their patients in accordance with the best principles of vascular biology and physiology.

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From the [1]Department of Surgery, Uniformed Services University of the Health Sciences, Bethesda, Maryland; [2]Division of Vascular and Cardiothoracic Surgery, Walter Reed National Military Medical Center, Bethesda, Maryland; [3]Division of Hand Surgery, Walter Reed National Military Medical Center, Bethesda, Maryland.

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Address for Correspondence: Eric Twerdahl, MD, Walter Reed National Military Medical Center, 4494 Palmer Road N., Bethesda, MD 20814. Email: eric.h.twerdahl.mil@health.mil